APOLLO LUNAR SCIENCE PROGRAM

REPORT OF PLANNING TEAMS

(NASA-TM-X-69117) APOLLO LUNAR SCIENCE PROGRAM REPORT OF PLANNING TEAMS. PART 1: SUMMARY (NASA) 37 p

N73-71696

Unclas
00/99 16967

PART I. SUMMARY

Lunar Science Branch
Manned Space Science Program Office
Office of Space Science and Applications
NASA Headquarters
Washington, D.C.

June , 1965

CONTENTS PAGE

INTRODUCTION

This report summarizes the recommendations of specialized planning teams which were convened to give detailed consideration to scientific aspects of the approved missions of the Apollo space science program. It is important to view these scientific aspects within the framework of the general planning of the lunar and lunar-earth science program of the National Aeronautical and Space Administration.

A. General Planning of the Lunar and Lunar-Earth Science Program

To observe the detailed structure of the Moon and from these observations to improve our understanding of the history of the Moon and of the solar system - such, in broad outline, are the objectives of the lunar and lunar-earth science program. Precisely because these general objectives of the lunar and lunar-earth science program are multipurpose ones to be executed by a multi-discipline scientific community, fundamental studies should be made on:

1. The solid Moon itself, including:
   Chemical and Physical constitution,
   History of development of the lunar landscape,
   Lithologic, mass distribution and thermal gradients,
   Internal constitution as expressed by tectonics and vulcanism,
   Mechanical and chemical processes of aggregation and disintegration,
   Sampling of elemental abundances of the Moon which, in addition to the knowledge of the terrestrial (Earth) elemental abundances should greatly increase our knowledge of the abundance of elements of the solar system, and contribute to a model with which to test basic theories of the origin of particles and elements,
   Meteoritic collisions and their use for lunar seismology.
2. The gravitational and magnetic field forces centered around the Moon, and their interaction with those of the Earth and

other planetary bodies. Simultaneous gravity measurements should be taken on the Earth and the Moon for the detection of gravitational waves.

3. Particles, such as solar protons and cosmic radiation, and their effect on the lunar magnetosphere as well as the effect of this bombardment on the lunar surface materials.
4. Possible evidence of extra-terrestrial life or photo-organic matter.
5. Various stages of evolution of the nebulae, stars and galaxies of the universe made from a lunar observatory in an environment free of atmospheric interference.
6. Modifications of the properties of materials in the lunar environment.
7. Experiments to test basic physical or chemical laws and constants in the lunar environment.

To accomplish the diverse studies needed to achieve the general objectives, NASA plans several series of closely co-ordinated missions to follow the recently completed Ranger series. Approved parts of the overall lunar and lunar-earth science program of NASA include: the Surveyor series of unmanned soft-landing missions to telemeter back information from the lunar surface; lunar orbiters with capabilities for close-in observation of topographical or geological features and with remote sensing equipment for measurement of geophysical properties; the Apollo manned science program which would place astronauts and astronaut-scientists on the lunar surface for brief stays and achieve the return of lunar samples for detailed earth-based studies. Planning is also advancing in manned lunar orbiter and in Apollo extended-stay missions. Descriptions of these other phases of the overall NASA program are included in the publication "Opportunities for Participation in Space Flight Investigations" published in January, 1965 by the NASA Office of Space Science and Applications. The sections which follow will be restricted to detailed consideration of the approved parts of the Apollo manned science program.

B. Specific Objectives of the Science Program for Approved Apollo Missions

The broad objectives of the Apollo Science Program were outlined following the National Academy of Science Iowa Summer Study June 17-August 10, 1962. Three types of scientific tasks were identified as those which could most profitably be carried out by scientist-astronauts during early missions of the Apollo program:

(a) Observations of natural phenomena including macro and micro structure,

(b) Collection of representative samples,

(c) Emplacement of monitoring equipment.

Since 1963 specialized planning teams have considered individual aspects and extensions of the recommendations of this Iowa Summer Study. Their findings have made it possible to describe in detail the following realistic specific objectives for approved missions in the Apollo lunar science program:

The study of the surface and near-surface features and composition of the Moon by geological and geochemical techniques,

The study of the interior constitution of the Moon and its graviational and magnetic fields by geophysical methods,

The study of the lunar atmosphere or the lack of it,

The search for living matter or proto-organic matter on the Moon.

The Geological exploration of the Moon includes the study by astronauts or scientist-astronauts of landforms, structures and the processes constantly modifying them, such as meteoritic impacts, vulcanism, tectonics, and bombardment by particles of the solar winds and micrometeorites etc. It includes the study of the particulate, fragmental materials and bed rocks on the lunar surface of both shallow and deep orign.

Geophysical exploration, to be carried out and closely correlated with the geological exploration, includes the study of the constitution of the interior of the Moon by passive and active seismic methods; the lunar heat balance by heat flow measurements, and the study of the magnetic and gravitational fields by both surface instruments and in conjunction with manned lunar oribtal observations.

The lunar atmosphere exploration, carried out in conjunction with the geophysical and geological investigation, includes determination of the density and mass spectrum of any lunar atmosphere and possible sources and sinks for gaseous molecules on the surface.

The planned geochemical exploration differs from the foregoing investigations in that it is envisaged that the major scientific achievements will result from detailed geochemical analysis of samples after their return to earth in suitable containers. No quantitative chemical analysis is planned on the lunar surface during the early Apollo missions and geochemical studies would be restricted to those which positively aided selection of a representative group of samples or which would be unobservable after sample return to earth. Significant answers to the central questions of the origin and history of the Moon and their relation to the origin and history of the solar system can best be obtained by exhaustive earth-based samples on returned lunar samples. These should include: gamma-ray measurements, surface structure and properties, analysis of evolved gases, mineralogy, micro and semi-microanalysis, x-ray fluorescence, isotopic-ratio determinations and neutron activation analysis.

The search for living matter or proto-organic matter on the Moon would also emphasize principally the return of samples to earth and their detailed examination by bio-organic techniques.

C. Benefits of the Specific Objectives

The justification of the specific objectives of the lunar science program need not be more than the search and increase of human knowledge. There are, however, many reasons why this program should be vigorously supported from the scientific point of view:

1. The comparative study of the Moon and the Earth will greatly increase our understanding not only of the origin of the Earth-Moon system, but also of the composition and the origin of the solar system.
2. There are many geological problems on Earth which because of the sedimentary cover and the modification by the agents of the atmosphere and hydrosphere can not be studied directly. These problems involve the processes such as magmatic differentiation and metasomatic replacement of ores which directly influences the distribution of the elements and concentration of mineral resources. It is hopeful that the solutions to these problems and the processes involved may be clearly displayed and more susceptible to study on a lunar surface not modified by secondary processes as on Earth. The results may have direct bearing towards more intelligent search for mineral resources on Earth.
3. The basic crustal tectonic forces and mechanism of mountain building may also be in grand display on the lunar surface. The understanding of these forces may help to interpret the forces which shape the Earth's configuration and influence the physical environment upon which the development and migration of human civilization depend.
4. The always possible existence of the "unexpected" scientific accomplishment is perhaps more real than fanciful. Curiosity and anticipation of discovery are the driving forces of our civilization. If the lunar science program is not pushed vigorously now, it will be later. Lunar exploration by manned spacecraft has been shown to be technologically possible; its execution in order to satisfy human curiosity is inevitable. With the national goal of Manned lunar landing set for 1970, thorough and intelligent planning for the lunar science program is needed now.

It should be kept in mind in reading the experimental programs in the following sections that: (1) the attainable objectives of the Apollo lunar science program for approved missions are necessarily limited because of the restricted stay time of not more than 24 hours, and the restricted mobility of the astronaut; (2) in order to accomplish the broad general objectives outlined previously for the overall lunar science program, it is planned to extend the basic Apollo science program by means of an advanced Apollo with longer stay time on the Moon, and greater mobility and logistic support; (3) detailed geological mapping, which should and can only be done with longer stay times, would be made possible by this extension of the Apollo program and by the greater areal coverage afforded by manned orbital missions; and (4) use of the Moon as a base for deep-space studies in astronomy or for detailed investigation of physical or chemical processes and properties in space would be deferred until later phases of the NASA lunar science program.

II. PLANNING OF SPECIFIC TASKS FOR APPROVED APOLLO MISSIONS

Several committees were convened to consider how attainment of the scientific objectives of the Apollo science program could best be planned for in their area of specialization. The recommendations of the planning teams are summarized here under the following headings:

A. Realistic tasks to be completed on the Lunar Surface in the short stay time of approved Apollo missions.

B. Field observations to be made during stay time on the lunar surface.

C. Recommended schemes of sample recognition, sampling tools, sample containers and sampling techniques for choice of representative samples for return to earth.

D. Recommended procedures for handling, unpackaging, preliminary inspection, detailed investigation and data correlation on samples returned to earth.

E. Training of astronauts necessary for optimum performance of tasks assigned to them.

F. Requirements and objectives of earth based geophysical investigations originated through equipment emplaced on the Moon by the astronauts.

G. Special biosciences aspects of the approved Apollo missions. The following paragraphs, present the necessary background information advanced by team members in support of their recommendations.

A. <u>Realistic Tasks</u>

The consensus of the <u>field geology</u>, <u>mineralogy and petrography</u>, <u>biosciences</u> and the <u>geochemistry planning teams</u> is that because of the short few hours stay time of the early Apollo landings and the limited mobility of the astronauts, the major scientific task of the early Apollo landings should be the selection of representative samples (60-80 pounds limited by the capability of the spacecraft) for return to earth.

It is also the consensus of these planning teams that no quantitative analysis be done on site because of, (a) the limited stay time, (b) the non-existence of automated, miniaturized analytical instruments which can perform reliable and comprehensive quantitative rock or soil analysis and, (c) the greater capability of well-qualified earth-based laboratories to study and analyze the returned lunar samples in detail under carefully controlled conditions.

Other important tasks identified by the <u>field geological planning team</u> are to obtain, so far as is possible, complete and accurate knowledge of the nature and structure of the lunar surface, and of the regional stratigraphic and petrologic character of the field relations at each Apollo landing site. Such observations are essential for the complete interpretation of most later chemical, physical, mineralogical, petrographic, and biological analysis upon the collected samples. They are indispensible for the correct interpretation of most physical measurements of the lunar surface that can be made at these sites.

An important practical distinction between the tasks just described and those which follow is that the former are capable of completion without extensive additional equipment beyond that needed, in any case, for communication between the LEM, the astronaut on the surface, and the earth-based control and data receiving facilities. The following tasks would require, in general, emplacement of a telemetry system to remain on the surface after departure of the LEM:

The passive seismic planning team identifies as realistic the emplacement of a single 3-axis seismograph by an astronaut, whose duties might be as simple as placing the equipment on the lunar surface or as complex as adjusting the band-pass and gain of the instrument to allow for lunar seismic noise.

The active seismology planning team desire only that the astronaut emplace geophone(s) and emplace and aim a mortar package. Performance of such active experiments could be deferred until several months after set up and departure.

Tasks recommended by the lunar atmosphere Measurements Team would be directed to measure the total pressure, mass spectrum, of neutral species and the total concentration and mass spectrum of ions together with their directional flux. The possibility of leaving behind a mass spectrometer package to telemeter lunar atmosphere over a long period seemed to be most desirable to this team. Setting up charged particle analysers on the lunar surface to examine the energy spectrum of both positively and negatively charged particles and their directions of arrival, together with an ion mass spectrometer and ion trap is recommended for information on the ionized component of the lunar atmosphere. Pressure gages were also recommended for all missions to be deployed so that time variations at different locations could be interpreted to give information on possible lunar sources of gases. They could also be used to give information on any "clean-up" of the lunar atmosphere by escape of rocket gas contaminants after departure of the LEM.

The lunar gravity measurements team envisages emplacement of an instrument of total weight less than 30 lbs, with simple provision for temperature control and minimal channel requirements to telemeter back information. Observations of lunar tides, search for free oscillations, and the use of the Moon as a detector for gravitational waves, are important scientific points which this team associates with emplacement of a sensitive gravimeter of a modified La Coste Romberg design.

Location of a triaxial vector magnetometer instrument with a dynamic range of several hundred gammas and a sensitivity of fractions of a gamma, with appropriate analog to digital conversion subsystems, appeared realistic to the lunar magnetic measurements planning team. Although the team also has great interest in earth-based magnetic measurements upon returned fresh samples of unweathered, physically-stable lunar material, the anticipated need for drilling techniques to recover such samples makes it uncertain whether suitable samples for "magnetic memory" measurements would be obtained in early missions.

The Heat flow planning team propose that the astronaut emplace on the Moon three simple thermal experiments with the objectives of telemetering back measurements relating to the surface heat flux, the surface temperature fluctuations and their propagation into the subsurface, and the thermal properties of lunar surface materials at several locations. Of these three experiments, those to measure temperature as a function of depth and time in lunar surface material penetrable to 50 cm or less, or to make similar measurements in surface material beneath an area disturbed by an insulating blanket, would not require drilling holes, but the third experiment has that requirement.

B. Field Observations

From available data, the field geology planning team contends that it appears highly probable that most parts of the Moon's surface are covered with a layer of finely broken rock fragments, the upper surface of which is pitted with craters. The thickness of the layer, the size distribution of the rock fragments, and the size and spacing of superimposed craters probably all vary abruptly from place to place. They believe that from the photographs acquired from Ranger VII, in addition to the information obtained at the telescope, a reasonable model of the fine structure of a typical local area on a mare surface can be described as follows: A layer of shattered and pulverized rock ejected from nearby craters, covers more than 95 per cent of the mare. It is of variable thickness and rests with irregular contact on the underlying substance of the mare. The debris layer typically varies in thickness from a few tens of meters to less than a millimeter. The upper part of the debris layer consists of finer particles than those fragments near the base, due to more frequent stirring up by small cratering events.

Examination of such a debris layer, and verification or reinterpretation of such a model, presents a challenging problem for the astronauts. Features to be described, in addition to tentative identification and classification of the fragmental material, include size and spacing of the fragments, and nature of the craters and of all other small and large elements of the local topography. Observations along the wall of a nearby crater, and digging and probing of the debris layer by a suitable tool will help to gain an understanding of the vertical distribution or layering of the debris layer. Selection of samples representative of the landing site will not be an easy task. The success of the field geological observations and sampling will depend in large measure upon the training of the astronaut but there is need also for adequate equipment for communication and tracking at all times between the astronaut on the surface, the LEM, and the earth-based investigator teams. Such adequate communication would be of value not only for field geological studies and selection of the most valuable samples for return to earth, but also in the choice of optimum positions for emplacement of the equipment for lunar atmosphere studies and those recommended by various teams for geophysical studies. A delicate balance must be established between the requirements of the tasks assigned to the astronauts and the provision of adequate time and flexibility to adjust to and make observations upon the 'unexpected' or unusual in these field observations. Much flexibility may, for example, be needed in discerning unusual properties imparted to topmost layers of dust or aggregated particles by radiation. Valuable information may also result from measurement and control systems on the LEM during its stay-time on the Moon, such as information on solar radiation from the radiation monitoring equipment. Field instrumentation to be carried by astronauts in their traverses from the LEM would be mainly incorporated into a specially designed Jacob's staff and could include (i) vidicon camera, (ii) film camera, (iii) ionizing radiation detection system, (iv) and a calibrated penetrometer.

C. Sampling

The interest, enthusiasm, and diversity of groups wishing to make measurements upon returned lunar samples is expected to be so great that no one batch of samples from a single Apollo mission could completely satisfy them. It is therefore important to recall that several missions have been approved and that preferences of various disciplines for various types of sample may be satisfied by different missions, and in fact the biosciences team has indicated interest in receiving samples from each of the approved missions.

Careful attention to sampling tools, sample recognition, sampling techniques and sample containers were recognised as highly desirable by several planning teams. Their conclusions from detailed discussion are briefly presented below. Although teams commented on the desirability of developing simple portable equipment to aid in the choice of representative samples, the nature of such equipment was not clearly defined, and choice of the preferred samples appears dominated by the requirements of earth-based measurements to be made on them.

(a) Size of Samples: The field geology team suggests that most of the samples collected should not be large, that a sample 1/2 x 1/2 x 1 1/2 inches is more than adequate for most purposes. As many samples as possible of this size consistent with the sampling scheme should be collected. A few large samples would perhaps also be desirable for special measurements of physical properties and as standards for interlaboratory comparisons. Small samples of surface debris should be collected to fill in the remaining space allowed.

The mineralogy and petrography team would prefer large individual samples of solid material, which are representative of the landing site. These samples should range in weight from a few pounds up to 5 or 10 pounds. Small pieces become more justifiable if of a widely diverse nature or if of exceptional interest. A mixture of samples to be taken might consist of larger pieces representing bed rock or the more abundant or representative part of the landing site. In addition a large sample of loose superficial fragmental material should be taken.

The geochemistry planning team made similar suggestions, but for study of radiation and induced radioactivity, the tops of the samples should be known. A special technique should be adopted to collect a specific sample for the measurement of lunar gas content of the sample. It should be of a special design of perhaps a type of sampling tube which can be sealed prior to return.

The bioscience planning team identified as their ideal case collection of many 1 gram samples of finely divided material from different localities (all from sub-surface and permanently shaded spots) plus several sub-surface 500 grams to 1 kilogram samples. In an acceptable case, several 1 gram samples and one to two large samples collected as above would be valuable. Anything in any form the astronauts can bring back, would meet the minimum requirements of this team.

The lunar magnetic measurements team suggest that 3 or 5 samples of fresh unaltered lunar bedrock samples be obtained from any location by a 1 inch diameter drill at depths of less than 1 meter. It is important that the orientation of the samples obtained be determined with respect to a lunar set of coordinates to an accuracy of 5° as well as the relative location of the sample sites. These team members are aware that drilling may not be accomplished during the first seven Apollo Landings.

The heat flow planning team and the seismic study planning teams did not specify studies of returned lunar samples. However the physical properties of the samples such as thermal conductivity, diffusivity and wave velocities through lunar material should also be considered for Earth-based studies.

A tentative conclusion with regard to sample selection therefore would require:

representative bed-rock samples weighing 5 to 10 earth pounds for extensive detailed mineralogical petrographic, geochemical as well as geophysical measurements.

A large number of pieces 1/2 x 1/2 x 1 1/2 inch or small size fragments of various rock types

many small particulate materials from shaded spots or from depths for bioscience investigations

a large "dust" sample collected for detailed laboratory study of the various rock types which this sample might contain.

If the sample return compartment has remaining space, small samples of surficial debris can fill it. Drill core samples may not be obtained depending on the development of a light weight, portable drill. Hopefully large, fresh, unaltered samples will be suitable for geophysical measurements. A special sample will be collected for gas analysis. If the lunar surface consists of rocks other than chrondritic meteorites, then meteorites, which are responsible for much of the lunar sculpture should also be collected for study.

(b) Sampling methods and techniques: Sterilized geological hand tools, modified or adapted to the lunar environment should be used as collecting tools. Loose material may be collected by the sterilized sample scoop of the surveying staff. The need for the development and testing of geological hand tools in simulated lunar environment is emphasized.

(c) Sample containers and packaging: Evidently, the types of sample containers and methods of packaging and sealing are of great concern to most members of the planning teams. It is clear that studies should be initiated as soon as possible for container material which is stable in a simulated lunar environment. The container should be flexible in size and shape and able to accommodate the various sizes of the samples collected. It is also evident that if there should be trade-off of sample weight against container weight, relaxation for preserving the lunar environment is recommended to conserve as much sample weight as possible. This consensus results from the following considerations advanced by the individual teams:

The field geology planning team indicated that most of the samples collected should be placed in individual, pre-numbered, gas-tight soft bags, and the bags placed in gas-tight, pressure proof, rigid sample boxes which will be sealed outside the LEM before return to earth. Besides the soft bags, several small, rigid containers should be available so that unconsolidated material such as dust samples can be taken and their structure preserved.

The mineralogy and petrography planning team indicates that sample containers be adaptable as to size and shape, be non-contaminating, have strength and thermal stability and stability in hard vacuum, and be light weight and easy to use. Individual samples, particularly those that may be volatile or otherwise unstable, should be packaged separately to eliminate contamination and mixing. The samples should be stored and kept at temperature not higher than the lunar environment. The top side of samples should be identified if necessary and the containers or samples should be clearly labeled and properly logged-in with voice description, location and photographs. A few grams of representative sample should be packed in hard vacuum, and the trade-off in terms of container volume and weight should be small, but other samples need not follow such stringent packaging requirement. Ideally, the samples would be returned in sealed, sterile containers that will exclude terrestrial contamination and maintain the lunar environment. If demanded by circumstances, any yielding in these idealized specifications should be made first with regard to maintaining the lunar environment, second with regard to terrestrial contamination and finally in sample size. If the worst happens, as in a land-and-run situation where recommended procedures can not be met, a full sample nevertheless should be taken and returned even if in an open condition. If the weight of sample containers to preserve the lunar environment proves to be a large fraction of the total sample load, or if containers can not be devised to accommodate a large single piece of rock except at high cost in terms of container parameters, then again this team recommends relaxation of the specifications preserving lunar environment, since the hazard from possible interaction of the sample with the terrestrial environment is felt to be small in view of the slow kinetics of the processes that would be involved. The return of even an unpackaged sample would in all probability permit realization of the main mineralogical and geochemical objectives and also permit evaluation of any terrestrial interaction that did take place.

The geochemistry planning team realized that sampling and packaging methods should be the first task to be developed. This development should consider our ignorance of surface conditions of the Moon. Two extreme attitudes are involved:

1. No effort should be spared to make sampling and packaging conform to the highest standards that now exist or can be developed so that a <u>small part</u> of the total samples preserves the

lunar environment. 2. Any sample obtained under even half-way decent conditions will be extremely valuable. Sample containers should be made of a clean, sterile, and easily identifiable non-magnetic material, and should be easily vacuum sealed. The existence of a hard vacuum on the lunar surface makes gas contaminants a secondary objective for most surface materials. Possibly for some samples high pressure and refrigeration would be needed. The team recommends that only a small fraction of the sample, for example about 500 grams(approximately 5 per cent total weight or volume) needs to be packaged in hard vacuum, the rest in vacuum of 10^{-6} Torr (contamination free containers) should be quite adequate.

The bioscience planning team indicated that under ideal conditions, hermetically sealed, metal, clean-and-sterile containers be used, placed in inert gas pressurized storage compartment of the LEM. This team reiterated the necessity of metal containers for the samples to be used in the search for both organic compounds and microorganisms, since exposure to any kind of plastic container would be ruinous, particularly for the organic compound search.

(d) Additional sampling problems: The field geology and geochemistry planning teams suggest the need of a study of the sampling scheme. Evidently the need of a carefully planned sampling scheme depends upon some knowledge of the landing site, the diversification of rock types, the percentage of consolidated and loose material, and the geological features. Because of the limited mobility and limited areal coverage, the geological features encountered and the rock types encountered may be few in number.

A sampling scheme is perhaps more useful with lunar geological exploration covering larger areal extent, and the scheme should be developed with respect to this objective. Consideration is being given to the question of whether the samples to be returned to earth should be chosen according to a predetermined pattern or by a more random selection process.

The geochemistry planning team also suggests that the development of portable instruments to help indicate diverse lunar rocks should be encouraged, particularly if visual examination is impeded either by space suit constraints, poor illuminating condition, or the darkening effect of cosmic and solar particle bombardment which could obliterate rock surface characteristics. The difficulty of visual inspection however, will be improved if fresh rock surfaces can be broken open by the use of suitable geological hand tools.

D. Ground-based studies of returned lunar samples:

Since results of ground-based studies of returned lunar samples, in the opinion of several planning teams, constitute the major scientific accomplishment of the approved Apollo Landing missions, detailed planning is necessary to produce the maximum amount of information. Every attempt should be made to obtain definitive answers to fundamental questions regarding the Moon, its composition, and whether differentiation has occurred. Evidence of processes which produce the lunar surface features, textures and properties will be valuable.

Upon return of the lunar samples, two stages of investigations are visualized by the teams:

First, unpackaging and preliminary study behind biological barriers of all the samples returned, to obtain a general idea of the types, amount and nature of the samples collected and to make measurements such as induced radioactivity, which demand immediate execution;

Second, detailed systematic laboratory investigations by different qualified experimenters with initial emphasis on non-destructive tests. It is generally assumed that these detailed studies will be done at various well-established laboratories.

Unpackaging and preliminary study: Unpackaging of returned lunar samples was disucssed extensively by members of various planning teams and it was generally agreed, and specifically mentioned by the geochemistry planning team, that a central storage and unpackaging facility of modest scale is required and be located as MSC Houston. Facilities for cleaning, handling and manipulating samples behind bacteriological barriers should be available. This receiving and unpackaging facility also serves the purpose of quarantine of the samples for examination by bioscientists for viable micro-organism which may back-contaminate the earth's environment.

Unpackaging procedure: Although unpackaging in a hard vacuum simulating the lunar environment is desirable, specific procedure for unpackaging was not discussed. Since the unpackaging procedure is important and is related to control of contamination during transfer from vacuum to atmospheric conditions, a small vacuum chamber and an array of cabinet-type biological barriers seem well suited for this purpose. The details have been worked out by a special ad hoc committee.

Preliminary studies: After the returned lunar samples are unpacked and successfully transferred from sample containers behind the biological barrier, a detailed description of the amount, general rock type, and sample locality should be made. An examination of loose grains from the samples by binocular and petrographic microscopes will probably be sufficient to classify the samples so that a detailed mineralogical, petrographic and textural study of the samples can be planned. This is necessary to properly plan the detailed studies briefly outlined below. Revisions of this plan may be necessary depending on the types of samples returned. Preliminary examination will also allow the selection of a large representative sample for low level counting of decay of cosmic ray induced nuclides. Gas analysis will be done on a specially collected sample at a well established laboratory. It is generally advisable to complete the mineralogical and petrographic studies prior to detailed chemical, isotopic, chronologic, geophysical and engineering investigation. However the mineralogy and petrography team requires no analytical or x-ray examination of the sample during the time that it is in quarantine.

The geochemistry team suggests requirement of one (but at the most two) elemental monitoring instrument where only the source needs to be located behind the biological barrier. One such instrument might be an optical emission spectrograph. Neither the mineralogy and petrography team nor the geochemistry team has requirement of any sort of experiment to be performed on the samples in vacuum of the order of 10^{-12}Torr.

Samples of fine-grained particulate lunar material meanwhile will be studied behind the biological barriers for possible viable microorganisms which may back contaminate the earth. Detailed search for proto-organic matter and possible living matter can proceed after the quarantine period is over.

Detailed mineralogical and petrographic studies: The detailed studies of samples will begin after the quarantine period is over and samples are distributed. Emphasis will be on the use of methods which are nondestructive or consume mimimum amount of samples. Measurement of physical properties such as specific gravity, luminescence, phosphorescence, indices of refraction, hardness, and magnetic susceptibility should be made first. This can be followed by the study of loose grains, thin sections, and polished sections without consuming more than a fraction of a gram of the respresentative sample. Samples which show macroscopic evidence of shock metamorphism, or samples which contain minerals not readily identified will be studied by x-ray diffraction, microchemical, x-ray fluorescence and the use of the electronprobe. Large representative lunar samples weighing several grams will then be studied systematically by chemical analysis of both the major and minor elements using not more than 250 milligrams of samples. A split of the sample can also be used for isotopic studies and age determination.

Detailed chemical studies: Major elemental composition (Si, Al, Mg, Mn, total Fe, Ca, K and Ti) can be analyzed by x-ray fluorescence method using small (10 mg) to 250 mg samples. Ferrous iron, Na, and H_2O will be done on separate samples.

17 minor elements (Ag, B, Ba, Be, Co, Cr, Cu, Ga, La, Mn, Nb, Pb, Se, Sr, V, Y, and Zr) can be done by quantitative spectrographic methods using 10 mg. of sample and 40 more minor elements, if present, can be determined semiquantitatively. Rb, Li and Cs can be done spectrographically on separate samples weighing a few milligrams. Additional small samples are to be used for elements susceptible to determination by neutron activation analysis.

Depending upon the potassium content of the sample, about 500 milligrams of sample will be needed for the K/A age determination, 50 milligrams for Rb/Sr age determination, and 40 milligrams for duplicate O^{18}/O^{16} determination. Other age determination techniques can also be planned or applied.

For other isotopic studies, larger samples will be needed. for example, the measurement of Al^{26} and Be^{10} by gamma-gamma coincidence spectrometric methods, or the amount of rare gases that may be present by mass spectrometric methods. Other stable, radioactive, and extinct isotopes (Xe-129) can be investigated on properly chosen samples.

Geophysical and engineering investigations: In order to help interpret the lunar geophysical data obtained by the deployed geophysical experiments, thermal conductivity, emissivity, electrical conductivity, and seismic velocities of various types of samples should be measured. The magnetic properties of samples of known orientation will be measured for use in the interpretation of paleomagnetism of lunar rocks.

It is expected that determination of the bearing strength or friction characteristics of lunar material should be done on the lunar surface. It is also important to determine the engineering properties of the various lunar samples such as compressive strength, shearing strength, porosity and permeability, resistance to abrasion etc. A better understanding of the engineering properties of lunar rocks will be needed for planning the construction of structures on the lunar surface for extended scientific exploration.

Bioscience investigations: The basic study is the search for living matter or proto-organic matter which may represent the precursors of life not yet activated by the earth's environment. The chances of finding such matter is not considered large, but a serious attempt will be made.

The study of lunar samples is treated in greater detail than other experiments because it will provide the most important scientific discovery - the composition of the surface material of the Moon. The samples will tell us whether a chondritic model fits the origin of the moon, and, therefore, will further clarify the chemical or genetic relationship of the earth and its moon. If the lunar samples resemble tektites in structure and are high in silica (more than 70%) then tektites are of lunar origin, and the Moon must be differentiated and has a core. The scientific implications are manifold. These implications can not be explored unless lunar samples are returned for extensive and detailed ground-based analysis.

Selection of investigators interested in the study of returned lunar samples: These samples are the center of attraction of the scientific community many of whom wish to participate in the making of various types of analysis and measurements on them. The need of selection of investigators will arise because of the limited amount of samples returned, which will not be enough to satisfy all demands. The geochemistry planning team discussed a way to screen applicants for the study of lunar samples through a procedure known as a "dry run". One or two standard samples of possible lunar material will be prepared by institutes such as the National Bureau of Standards or the U. S. Geological Survey and be made available to applicants who wish to make a specific type of measurement. The results of measurements made by the applicants will be evaluated by a screening committee to be selected and approved by OSSA of NASA. A great deal is to be gained from such a trial run. Firstly it will provide an opportunity to enumerate the types and significance of measurements that various investigators of the scientific community wishes to make. Secondly, interlaboratory comparisons will help to improve the measurements made and to gain insight into the problems of the study of such samples. Experience gained may also suggest various precautions on sampling and methods of sample return. Discussion is presently underway for initiating such a trial run, beginning with suggestion of how to obtain good standard samples. The biosciences planning team felt that a dry run would not be applicable to biosciences work.

E. Astronaut's training:

There are three major scientific aspects of astronaut training. These aspects emphasize earth sciences and are related to the three major tasks he has to perform after landing:

1. Observation and description of geologic features both large and small, and the use of sampling and surveying tools.

2. Selection of samples and sampling points. Training should emphasize sampling techniques and criteria of representative samples. Ability to select specimens of scientific interest will be necessary on the moon as well as familiarity with types of laboratory studies including the search for lunar micro-organisms, and 3. Deployment and setting up of instruments for geophysical experiments.

Geological training of astronauts is in progress. Future expansion of the training curriculum in areas of geophysical experiments and biosciences should be undertaken.

F. Requirements of Earth Based Geophysical Investigations via Equipment Emplaced on the Moon

A great deal of information regarding the mass, lithologic distribution, and the structure of the interior of planet Earth was obtained by geophysical methods. The combined information on the free oscillations detected seismically, gravitational measurements, heat flow measurements, and the magnetic field and the magnetosphere have provided a shelled structural model of the Earth and predicted its compositional variation. Although the present model is by no means without serious difficulty, the geophysical methods are believed equally effective for the study of the Moon, in order to investigate its mass distribution down to its center, its passive seismic sources, its gravitation and magnetic fields, and its heat losses.

Recommendations of planning teams for geophysical investigation are grouped according to the type of study such as: seismology (utilizing both passive and active sources), magnetic field studies, measurements of gravitational fields coupled with search for gravitational waves and heat flow studies.

The method of investigation is to leave on the lunar surface automated long-life geophysical instruments such as seismometers, gravimeters and magnetometers. The instruments are to be emplaced by the astronauts and start functioning by some simple switching devices.

Although the precise geophysical instrumental package is at this time unknown, a seismometer, gravimeter, and magnetometer are likely to be successfully built in time for the early Apollo flights. The heat flow experiment is still in its conceptual development stage due to the non-availability of drill holes. Insulated thermal blankets to be deployed and emplaced by the astronauts show some promise as a means of carrying out such measurements.

As yet little consideration has been given to the handling and analysis of the large amounts of geophysical data telemetered back to earth. Exploratory discussions are underway to find a solution and to develop a reasonable handling procedure for data from the following investigations:

Passive seismology.

The passive seismic experiment proposes the use of a three-axis seismograph to record seismic waves from Moon quakes or meteorite impacts. These records will enable us to study the energy sources and the internal constitution and state of the Moon. Free oscillations of the Moon, if they can be recorded, make it possible for a single station to explore the lunar interior through to the center.

Lunar seismisity, that is the statistics of moonquakes, is an index of strain accumulation and release. It relates ultimately to the thermal history and the current thermal regime of the moon. Seismisity is also an index of the origin of surface features, such as faulting, volcanisms, and impacts. The correlation of lunar features with epicenters of seismic events will enable us to say something significant about the origin of the surface features. A single 3 axis seismic system on the Moon can give rough azimuths and distances, so that epicenters can be obtained with sufficient precision to make this correlation. Meteorite impact would provide seismic sources the same way that underground explosions do. These impacts would be difficult to separate from lunar quakes, except that the first motion would always be compressional. Roughly speaking, the seismic experiment is also a micrometeorite experiment with the entire surface of the moon serving as a sensor. Finally, seismic waves may be used to infer properties of the lunar interior. Body waves, could be used to reveal the presence or absence of a lunar core, velocity variation in depth and the mechanism of lunar tremors. The density-depth function in the moon can be recovered if the compressional and shear velocity structure is known. Thus the seismic experiment contributes to this important aspect of the lunar interior.

Design experience for the seismograph has been obtained from the design and fabrication of a single-axis short period seismometer for the Ranger program and the construction of a three-axis seismometer system for the Surveyor program. This latter system covers both intermediate, short, and long periods.

The three-axis seismograph for Apollo is designed to operate continuously for at least six months. It would be placed on the moon by an astronaut, who need only adjust the bandpass and gain of the instrument in the light of lunar seismic noise. The astronauts should be trained to perform this simple function.

The passive seismic experiment planning team also recommended that a single short period vertical seismometer weighing 10% of the three-axis system be included. It would serve as a backup device and to record short period body waves. This addition will decrease the band widths required for the long period seismographs.

It was estimated that a seismometer package would weigh less than 25 lbs. and be between 600 and 1200 cu. in. in volume exclusive of heat screens and power supply.

Active seismology.

The objective of the active seismic experiment on the lunar surface is to investigate the elastic properties of the lunar crust down to a depth of 500 feet. The experiment attempts to distinguish variation of lithology or rock types down to such depths. It involves the use of mortars to deploy explosive charges in a linear array uniformly spaced over ranges of 200 to 2000 feet. The seismic refraction is recorded by two geophones or receptors at 100 feet spacing. The astronaut would be required only to emplace the geophones, preferably buried, and emplace and aim the mortar package. This active seismic experiment will not be set off until the astronaut has left the lunar surface.

Heat flow measurement.

The objective of heat flow measurements on the lunar surface is to obtain information on the internal thermal region of the Moon which conceivably influences igneous and mountain building activities on the Moon. Heat flow measurements also provide basic data when properly interpreted on the thermal budget of the Moon and set limits on the model of the Moon's evolution.

An extensive program can provide enough data for proper understanding of the internal thermal region of the Moon. For the approved Apollo Landings, the experiment contributes the beginning of collecting the heat flow data.

The experiment is in its conceptual stage of development. The planning team suggests that the astronaut emplace three simple thermal experiments on the Moon. These experiments will enable us to learn about lunar surface heat flux surface temperature fluctuations, heat propagation into the subsurface, and the thermal properties of surface materials at several locations on the Moon's surface. The first experiment measures in a drill hole the temperature and conductivity at three points three to five meters below the surface. The second experiment measures the temperature as a function of depth and time by placing hand-driven probes with thermal sensors in undisturbed penetrable surface material. The third experiment measures by an insulating blanket, the temperature as a function of depth and time in surface material in a disturbed area. It also measures the heat flux through the blanket as a function of time. The second and third experiments will be carried out at several locations on the lunar surface. The first experiment can not be executed if a drill hole is not available.

Gravity measurements.

Precise measurements of the acceleration due to gravity on the lunar surface over a period of months may yield valuable information concerning the internal constitution of the Moon.

In 1916, shortly after the formulation of the General Theory of Relativity, Einstein predicted the existence of gravitational waves. There was no serious attempts to detect gravitational radiation until recently. Some years ago, one of the planning team members (Weber) suggested that the free oscillations of an elastic body would interact with gravitational waves and proposed the use of the Earth and Moon for the detection of such waves. According to Einstein's theory only the normal modes of quadrupole symmetry would be excited by gravitational waves. However some of the theories such as that of Brans Dicke, predict mono pole radiations. Unlike the earth, the lunar surface should be free of meteorological and oceanic disturbances. The use of the Moon as a huge mass quadrupole detector offers exciting possibilities. Correlation analysis of records obtained simultaneously on the Earth and Moon would permit the unambiguous detection of cosmic sources of gravitational radiation.

Observations are planned using a lunar gravimeter weighing less than 30 pounds, being less than one cubic foot in volume and having a power consumption of less than 5 watts continuously and less than 15 watts with 30% duty cycle. This device will continuously monitor the lunar gravitational field, recording changes greater than about one part in 10^9.

Sensitive gravimeters of the La Coste Romberg type would be suitable for this experiment if drift were further reduced and certain anomalies of the servosystem were removed. The present weight, power-consumption and environment temperature tolerance of this type of instrument can hopefully be redesigned to meet the needs of the lunar gravity investigations.

Magnetic measurements.

The objective of the magnetic experiment is to measure the lunar magnetic field strength. Results from Lunik II indicated this field could not be appreciably larger than the 100 gamma noise level of that experiment. It is possible that a lunar magnetic field could exist and would not have been detected by Lunik II if the field were compressed by the streaming solar plasma.

The most important aspects of the lunar magnetic field are its spatial and temporal characteristics. In order to adequately investigate the spatial properties of the lunar field and the interaction of the solar plasma with the moon, mapping by circumlunar satellites is required. This however constitutes a complimentary investigation not directly involved with the Apollo Landings.

A triaxial vector instrument with a dynamic range of several hundred gammas and a sensitivity of fraction of a gamma with appropriate analog to digital conversion subsystems is possible for use in this experiment within a weight limitation of 3 kilograms and a power limitation of 5 watts.

Lunar Atmosphere Measurements.

Measurements of the lunar atmosphere are of interest from an atmospheric physics viewpoint. Additionally, however, such measurements can be expected to significantly supplement the geologic data gathered on the moon, since the lunar atmosphere may have evolved from solid lunar material. Geology without lunar atmospheric studies, or vice versa, would unnecessarily increase the number of conjectures that must be made to properly appreciate the lunar evolutional process and its current state of evolvement. Since Apollo missions may contribute significantly to the contamination of the lunar atmosphere, it is important that measurements of the lunar atmosphere be accomplished as near the beginning of the program as possible.

The lunar atmosphere is known from optical measurements to be less dense than about 10^{-6} that of the earth's atmosphere (Dollfus, A., Ann d'Astrophysique, 19, 71 (1956)) and the ionized component is less than about 10^3 ions/cm^3, as determined by radio measurements (Elsmore, B., Phil. Mag., 2,1040 (1947)). Beyond these upper limits, all else is inferred, but estimates center about a concentration of about 100 metric tons for the total atmospheric mass. The Apollo excursion module will release up to 5 metric tons of exhaust gases. The above estimate involves important uncertainties, and the Apollo reaction products may even dominate the atmosphere. It is unfortunate that the vehicle carrying the atmospheric-measurement experiment may itself seriously contaminate that atmosphere, and the experiment should therefore be capable of operating for an extended period. At the very least, the loss rate for the contaminant gases can thereby be determined. If these loss rates are sufficiently large, then the atmosphere will return to its steady state and be observed by the lunar atmosphere experiment. Loss due to solar wind interaction may give rise to loss time constants of the order of one month, or about one lunar day. Thus the experiment should last, at the minimum, for several months. It is desirable, in any event, to observe any changes in the atmosphere that may occur between lunar day and lunar night, since this can provide further information on composition (e.g., the freezing out of volatiles during the very cold lunar night). The consideration of the Lunar Measurements Team relating to the emplaced equipment may be summarized as follows:

The maximum direct information on the lunar atmosphere must come from mass spectra measurements on the neutral components. However experimental techniques are presently better developed for measuring probable ionized components of the lunar atmosphere. The total neutral particle pressure can be measured with available techniques, and the mass spectrum may be measurable, depending on progress in instrument development in this area. Information should be obtained from emplaced equipment for several months after departure.

G. Special Bioscience Requirements

Special concerns of the bioscience planning team are: (1) the minimization of biological contamination of the Moon and of possible back contamination of the earth, 2) astronaut training, 3) sample collection, and 4) the laboratory facilities available at MSC for initial examinations of lunar samples. Of major interest are the search for lunar living matter and the search for proto-organic matter from returned lunar samples.

Minimization of biological contamination of the Moon: Biological contamination of the Moon may be caused by venting of the LEM, bacteria in its retro-rocket fuel, or leakage from astronaut's suit. The planning team believes that the outside of the LEM presents no problem because of the lack of lunar atmosphere to spread bacteria which might be on the outside surface of the LEM. The principal source of earth bacteria would be LEM's atmosphere. While on the Moon the atmosphere within the LEM should be vented through ultra-high efficiency biological filters. There are available filters with an internal flow resistence of only 2mm Hg, a particle (1-5 microns) retention greater than 99.99%, and a capacity of about 300 cubic feet per minute per square feet of filter area. When the LEM is opened after vacuum has been reached there will be no fluid medium to convey contamination to the lunar surface. Bacteria remaining inside the LEM should stay there, except for those carried by the astronauts themselves on their space suits and their equipment.

Bacteria, if present in the solid retrorocket fuel of the LEM that survives the burning during descent, might then contaminate the Moon. A bacterial examination should be made of the fuel, so that such contamination can be at least recognized. Monitoring of retrorocket fuel contamination is necessary because of the search for proto-organic or organic matter that might possibly exist in lunar materials.

Leakage of atmosphere from the astronaut's suit is the third major source of contamination. The bioscience planning team was told that current model of the space suit leaks about 200 cc of air per minute. The planning team recommends that using harmless bacteria, the bacterial contamination due to this rate of air leakage be determined. If the astronauts wear protective aluminized-fabric overgarments over their space suit, and if these overgarments are kept clean and sterile by wiping with a bactericide such as hypochlorite, then earth bacterial contamination onto the Moon should be further reduced. This space suit leakage contamination is not considered to be a serious problem.

The planning team also suggests that all equipment used by the astronauts or to be emplaced on the lunar surface be biologically decontaminated using ethylene oxide.

Minimization of possible back contamination to Earth:

The bioscience planning team consider very small the probability that any viable micro-organisms will be found on the Moon, and smaller still, the chance that, if they do exist, they will be dangerous. However, the problems with which we would be faced if lunar organisms pathogenic to animal or plant life were brought back and escaped could be so catastrophic that it can not be ignored, even though its probability be considered very low.

According to the planning team, everything that comes out of the command module after its returned to earth that has had an opportunity to be in contact with the lunar environment should be considered as a possible carrier for lunar pathogens. It would be advisable, at least, to wipe off, perhaps with dilute hypochlorite solution, all the outside surfaces of objects removed from the command module. Then the inside of the command module could be decontaminated with standard vaporphase bactericides.

According to the planning team, the most likely source of lunar pathogens, if indeed they exist, would be the astronauts themselves. Lunar organisms, even if not inherently pathogenic, could, acting in conjunction with terrestrial organisms in the nose and throat of an astronaut, produce disease. One would have to consider that any astronaut illness occurring within a few weeks after return would have to be thought of as potentially significant and therefore subject to strict isolation.

Scientists interested in the returned lunar samples will not immediately be in direct contact with the lunar samples. Scientific work on lunar samples which needs to be done quickly upon return can be done behind biological barriers.

The whole question of the possible return of lunar pathogens is considered to be a public health matter, and for that reason, the bioscience planning team feels that further expert advice and opinion should be sought.

Sampling in search of proto-organic matter and living matter from lunar samples:

The samples, sampling tools, sampling techniques and sample studies for bioscience investigations have already been discussed. It is perhaps important to point out that although lunar micro-organisms are not likely to be encountered, because of the lack of lunar atmosphere to sustain life and the wide temperature variation which are usually not tolerable to organisms, there is still a remote chance that such micro-organisms may exist at some shallow depths protected by an insulated blanket of lunar dust.

Perhaps the search for proto-organic matter shows more promise, particularly if the Moon's present condition represents a stage of the evolution of the earth during its early history prior to the emergence of primitive living forms. In this respect the returned lunar samples are potentially of great scientific interest with respect to the study of the origin of life.

III. ADDITIONAL PLANNING

A. Apollo Mission Profiles

The need for planning of mission profiles for the approved early Apollo Landings is vital, particularly because of the emphasis on efficient use of astronaut's time during the short stay on the Moon. This responsibility has not been assigned to any specific planning team.

Because of the constraints of the space suits and the astronauts' limited mobility, for a 4-hour stay time, the astronaut is not expected to make traverses of more than 1,000 feet away from the LEM. In order to effectively carry out a balanced scientific study of the landing site, precise function and time requirements to perform the mission should be known. Simulation of such time and function studies, with and without space suit constraints, are being carried out. A realistic mission profile must be developed and the astronauts should be trained to carry this out.

B. Apollo Extended System with longer stay periods for Geological, Geochemical and Geophysical investigations of the moon

As stated in the planning of the lunar science program, in order to learn about the Moon, extended geological geochemical and geophysical studies must be carried out with longer stay time. In addition extensive studies will be undertaken of particles and fields, and astronomy experiments utilizing an established lunar base.

Because of the limited ground coverage of geological traverses on the Moon, a lunar orbital laboratory, using primarily photographic and other sensing techniques, must be relied on for more extensive surveying and coverage.

It must be emphasized that post Apollo missions such as the Apollo Extension System or a Manned Lunar Orbiter are not approved programs but are under study as methods of increasing our Lunar exploration capabilities. Suggested scientific programs for these systems need to be closely integrated and coordinated with the approved Apollo experiments and results. Such studies will be released in separate volumes. The unmanned Lunar program (Ranger, Surveyor, Lunar Orbiter), the Apollo Program, and hopefully, post Apollo extensions will constitute the basic Lunar exploration program of NASA.

ACKNOWLEDGMENTS

The assistance of the following members of the indicated planning teams, whose many meetings made this report possible, is gratefully acknowledged:

Field Geology, Goddard, Mackin, Shoemaker and Waters;

Mineralogy and Petrology, Cameron, Chao, Frondel and Hess;

Geochemistry, Meinke, Gast, Clayton, Fleischer, Turekian, Mason and Arnold;

Passive Seismology, Press, Ewing, Sutton, and Kovach who were also members of the Active Seismology team together with De Noyer and Simmons;

Gravitational Field, Weber, and MacDonald;

Magnetic Measurements, Ness, Doell, Vacquier, Balsley, Madden;

Heat Flow, Clark, Langseth and Lachenbruch;

Biosciences, Calvin, Anderson, Bieman, Elbert, Haagen-Smit, Lemmon; Phillips and Tousimis;

Lunar Atmospheric Measurements, Francis Johnson, Testerman, Michel, and Spencer.

Membership on the Apollo Science Planning Teams does not prevent the scientists from submitting proposals to be named investigators or experimentors. In fact the members are encouraged to do so. Proposals will be evaluated by the appropriate OSSA subcommittee. Their efforts are greatly appreciated.